

**ACCURACY
OF
NEW BUILDINGS HIGH-RESOLUTION CLIMATE ZONE MAPS
IN A COMPLEX COASTAL MOUNTAIN REGION**

by

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SUMMARY

This document reports initial progress on a National Aeronautics and Space Administration (NASA) project to extend American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc./Department of Energy (ASHRAE/DOE) developed building codes maps over the entire globe. The effort is a joint activity by both NASA and DOE with coordination through ASHRAE Technical Committee 4.2. If successful, the maps will allow recently-developed ASHRAE buildings design manuals and buildings codes to be used over the entire globe instead of only in selected cities and towns which have weather stations (over 5,500 sites). This may lead to higher energy efficiency both in the United States and over the globe. The task also complements a World Meteorological Organization (WMO) effort to define and support a new sustainable buildings effort over the entire globe through a new version of WMO Technical Note 150, Building Climatology. The DOE Oak Ridge National Laboratory has recently developed, built, and demonstrated new construction techniques for small houses that approach zero energy use. It is possible that these design concepts may be adaptable in less populated regions of the globe if the DOE/ASHRAE climate zones are known in rural regions.

INTRODUCTION

A member of the WMO Technical Note 150 study team has estimated that:

1. Less than 500 million people live in ASHRAE-type thermal design communities.
2. Approximately 2 billion people live in simple buildings with no systematic design or energy supply.
3. Approximately 2 billion people are using four times more energy than necessary for heating and cooling because of the poor design of buildings and homes.
4. Approximately 2.5 billion people live somewhere in the middle.

ASHRAE is a leading international organization that develops very high quality procedures and manuals for the design of more efficient homes and buildings. Its standards and procedures are used internationally in many locations where extensive weather data measurements are available, mostly from airports near cities and towns.

NASA has partnered with WMO since 1982 to develop global measurements of surface radiation and weather data through advanced analysis of both satellite data and reanalysis models. The initial goal was to map various parameters over the entire globe on a 1x1 degree latitude/longitude cell size for at least 20 years to study climate changes in various remote regions. Since that time, technology has advanced such that many general and buildings-related meteorological parameters are now available at the NASA Surface meteorology and Solar Energy (SSE) web site (<http://eosweb.larc.nasa.gov/sse/>). The site was made possible by significant contributions from 8 industry organizations (see the Partners and Performance section near the bottom of the opening page of the above web site). As of November 2008, there have been 9,494,943 hits on the site and 1,757,427 data documents downloaded free-of-cost by both U.S. and international users from 116 countries. Users of both DOE's HOMER design software and

Natural Resources Canada's RETScreen design software are allowed to obtain data from the NASA web site without NASA registration. As of April 2008; NASA, HOMER, and RETScreen had over 30,000, 20,000, and 148,000 unique registered users, respectively. Additional information on users, data content, methods, and accuracies can be obtained from the home page of the above web site.

NASA is now working with several organizations to upgrade the SSE data. Improved spatial resolution over the entire globe is desired by many users. Present SSE data are values averaged over a 1x1 degree latitude/longitude cell. A long-term NASA goal is to provide satellite and reanalysis model data on a higher spatial resolution 10 x 10 minute latitude/longitude grid scale. A 1x1 degree latitude/longitude cell contains 36 of the smaller 10 x 10 minute cells. This report describes initial results in estimating both near-surface (i.e. 2-m) temperatures and DOE/ASHRAE buildings climate zones on the new 10 x 10 minute grid system over the globe.

The new approach employs the Goddard Earth Observing System Version 4 (GEOS-4) reanalysis modeled 1 x 1 degree cell-size temperature data which is then adjusted (lapse rate and offset) to the elevation of the United States Geological Survey (USGS) 10 x 10 minute topography heights inside the original 1 x 1 degree cell. The adjusted value is an estimated 2-m height surface temperature inside the 10 x 10 minute latitude/longitudinal cell. These new high-spatial-resolution temperatures are compared with National Climate Data Center (NCDC) ground-site measured temperatures in a complex coastal/mountain region in the northwestern U.S. Accuracy of 2-m temperatures and base 18 deg C heating degree day estimates are presented. These values are then used with satellite data to map ASHRAE building climate zones over most of the United States on a 10 x 10 minute latitude/longitude scale. NASA maps based on the GEOS-4 for the year 2004 are then compared with presently-available DOE/ASHRAE climate zone maps based on 1961 through 1990 NCDC ground site measured temperature data.

It must be noted that NASA does not advocate using satellite-based information if high quality ground site measurements are available for all buildings-related parameters needed for project design. Unfortunately, a complete array of desired parameters from ground site measurements near the proposed construction site is not always available. In this case, many users have found it practical to mix both ground site-measured and satellite/reanalysis-based data to obtain all parameters needed for the project, particularly during the preliminary design phase.

PRESENT SITUATION

The goal in this study is to test a practical method to adjust 1 x 1 degree cell temperatures either up or down to obtain temperature and temperature-related parameters either in a valley or near a mountain top. A secondary goal is to provide both near-surface temperatures and regional climate zone maps on a small 10 x 10 minute spatial resolution scale that may be useful for estimating climate zones relative to political boundaries.

Figure 1 illustrates the problem using 1 x 1 degree latitude/longitude temperature data for sites located in the mountains. The cross-section of a site (or 10 x 10 minute cell) located in the valley is compared to a dotted line which represents the average height of a 1 x 1 degree cell in the region. GEOS-4 temperature values are available for a 2-meter height above the average 1 x 1 degree cell. A procedure is needed to adjust the GEOS-4 1 x 1 degree cell temperatures (dotted line) either down toward the valley or up toward the top of a mountain, wherever 10 x 10 minute cells are located.

A NASA study has been completed to empirically define approximate correction equations using 1987 (1140 sites) and 2004 (2704 sites) NCDC data from over the globe. The study is described in <http://eosweb.larc.nasa.gov/sse/>. Go to Methodology, then Section VIII. Meteorological Parameters. An averaged GEOS-4 height-adjustment equation (T^{final}) is given as Eq. VIII-1. In our case the averaged adjustment equation between 10 minute and 10 degree cells is:

$$T^{(10-min)} = T^{(1-deg)} - [(H_{1-deg} - H_{10-min}) * \text{Lapse Rate}] - (\text{Offset}) \text{ where } H \text{ is the height above sea level in km.}$$

	Lapse Rate ($^{\circ}\text{C}/\text{km}$)	Offset
Tmax	-6.22	-1.29
Tmin	-4.66	+0.66
Tavg	-5.34	-0.10

It is quite informative to go to the next section (VIII-A.i. Climate Zones). Accuracy statistics are generated for 1987 highest-quality NCDC sites for each of the 8 DOE/ASHRAE buildings climate zones using the above equations. ASHRAE equations were used to calculate both heating and cooling degree days.

The public is allowed to obtain 10 x 10 minute topography data from the USGS. Figure 2 shows both 1-degree and 10-minute topography maps for the U.S. and Canada. Note that there are considerable terrain height differences between the maps in both mountain and coastal regions. These differences are illustrated for complex topography in the Pacific Northwest region of the U.S. and Canada in figure 3. It is in this type of region where we have chosen to demonstrate that GEOS-4 1 x 1 degree temperature results can be adjusted to a 10 x 10 minute elevation grid coupled with tests to evaluate the accuracy of the adjustment process. Figure 4 compares ground site locations (with heights) to the USGS 10-minute topography map.

Figures 5 and 6 compare Briggs et al. climate zone calculations with NASA estimates. (Briggs et al. climate zone definitions are shown in the TABLE at the end of the text.) Figure 5 is the original Briggs et al. map taken from the ASHRAE Colliver et al. report (ISBN 1-931862-55-9). This map is based on horizontally and vertically interpolated near-city ground site temperatures from the 1961 through 1990 period. Climate zone boundaries have been adjusted to match county boundaries because building codes are usually enforced by either county or city officials in the U.S. Figure 6 is the result of constructing 10 x 10 minute GEOS-4 adjusted temperatures (from the 1 x 1 degree GEOS-4 data) and estimating climate zone values using the Briggs et al. calculation procedure for year 2004 only. Considering differences in time period, the maps in figures 4 and 5 are quite similar in flatter regions of the U.S.

Figure 7 compares Briggs et al. and NASA climate zone maps for the very complex coastal mountain region in the northwestern part of the U.S. and Canada. Results from the two methods are quite different in some regions. The GEOS-4 adjusted temperatures are based on the 10 x 10 minute USGS topography shown in the lower part of figure 3. NASA climate zone maps (figure 6) are showing differences between mountain peaks and valleys to the East as well in other regions corresponding to USGS topography in the lower chart in figure 3. Comparing figures 5 and 6, both the Briggs et al. and NASA methods appear to

be in close agreement (considering time period differences) over flatter regions of the U.S. but differ in mountain regions.

VALIDATION

The next step is to determine uncertainty in the process of applying lapse rate corrections to the original GEOS-4 1 x 1 degree temperatures when estimating new 2-m average temperatures in 10 x 10 minute cells. It is necessary to compare lapse-rate-adjusted 10-minute cell values with NCDC ground site data within the cell. Unfortunately, this is not a precise process because the NCDC site will probably not be at the same altitude as the 10-minute cell average height in mountain terrain. We can expect some scatter in the comparison results.

Figure 7 shows both the 10-minute topography map as well as NCDC ground site measurement site locations. Most sites are at the lower altitudes, but some are in the mountains. Figure 8 shows 1 x 1 degree daily GEOS-4 temperatures versus daily NCDC site data without adjustment for altitude differences. Application of daily lapse rate corrections to adjust 1 x 1 degree temperatures to 10 x 10 minute cell altitudes is shown in figure 9. The altitude adjustment reduced daily bias by a factor of 3.8 and RMS error by a factor of 1.33. That type of result is difficult to observe in figure 7 because of the large number of daily measurements (16,809) included in the chart.

Figure 10 compares 1-degree GEOS-4 values (without adjustments) versus NCDC site values from within the 1 x 1 degree cells. Figure 11 follows a similar procedure except height adjustments are applied. Application of lapse rate corrections to the original GEOS-4 annual Heating– and Cooling-Degree-Days values improved correlation between NASA estimates and NCDC values.

There may be a question why the colored site-based data points (one for each of the 46 sites) did not group themselves by color since each climate zone mostly represents a different range of Heating Degree Days and Cooling Degree Days. Some climate zones have different heating and cooling degree day ranges depending on humidity and temperature range. The reason is that climate zone type is also a factor in defining the climate zone number as shown in the Briggs et al. table. Climate zone type was considered along with Heating- and Cooling-Degree-Days when defining the climate zones shown by the colors in figure 11.

It must be noted that figure 11 employs corrections between only the GEOS-4 10 x 10 degree cell heights and the 10 x 10 minute cell height used for high-resolution building code mapping. Elevation differences between a specific ground site within the 10 x 10 minute cell are not accounted for in the figure 11 charts. Direct application of the adjustment process to the GEOS -4 10 x 10 degree cells to an actual construction site altitude may improve the accuracy of the temperature estimates in steep terrain. From a practical view, however, care is required if significant small-scale, localized thermal influences exist such as heat-island, water body, or other local effects are present.

HIGH SPATIAL RESOLUTION GLOBAL MAPS OF DOE/ASHRAE CLIMATE ZONES

It is of interest to look at 10 x 10 minute spatial resolution DOE/ASHRAE climate zone maps over the globe. The reader is cautioned, however, these maps are only for year 2004. Figure 12 is a buildings climate zone map of the entire globe, and figure 13 is for the North American continent. Figures 14 and 15 show the South American and African continents. Figure 16 is larger in size to show individual

countries within Europe. Australia and the South Pacific region are shown in Figure 17. Finally, most of Asia is on figure 18. ASHRAE may be able to check some of the NASA international climate zone boundaries since it has ground site data for over 5,500 locations around the globe. Caution is required, however, because all results presented here are based on 2004 GEOS-4 data only. Boundaries may change in some regions in other years because of abnormal weather conditions.

CONCLUDING REMARKS

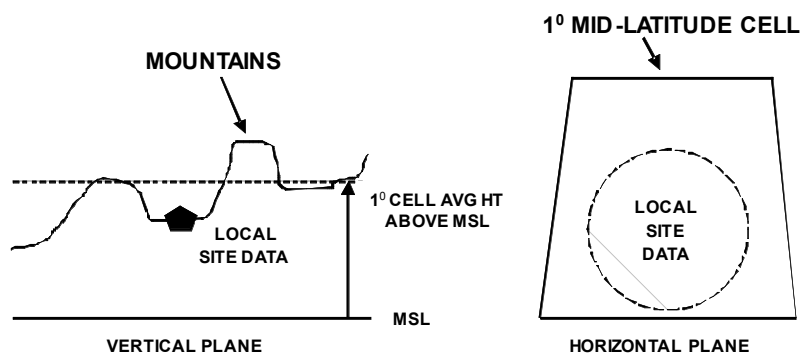
This study has demonstrated that estimates of 10 x 10 minute climate zone boundaries can be obtained when terrain-height adjustments are applied to GEOS-4 1 x 1 degree cell size temperature data in complex topography. The adjustment equation was based on highest quality NCDC ground site data in all DOE/ASHRAE climate zones. Additional follow-on tests similar to those in the northern U.S and Canada should be conducted in the difficult parts of the World. This might enable ASHRAE buildings manuals to be used in most parts of the globe even if ground site data is totally not available. Again it is emphasized that results shown here are only for 2004. Some differences may occur in other years in some regions.

TABLE: DOE/ASHRAE BUILDINGS CLIMATE ZONE DEFINITIONS

Zone No.	Climate Zone	Thermal Criteria
1A	Very Hot Humid	$5000 < \text{CDD}_{10\text{C}}$
1B	Very Hot Dry	$5000 < \text{CDD}_{10\text{C}}$
2A	Hot Humid	$3500 < \text{CDD}_{10\text{C}} < 5000$
2B	Hot Dry	$3500 < \text{CDD}_{10\text{C}} < 5000$
3A	Warm Humid	$2500 < \text{CDD}_{10\text{C}} < 3500$
3B	Warm Dry	$2500 < \text{CDD}_{10\text{C}} < 3500$
3C	Warm Marine	$\text{HDD}_{18\text{C}} \leq 2000$
4A	Mixed-Humid	$\text{CDD}_{10\text{C}} \leq 2500$ & $\text{HDD}_{18\text{C}} \leq 3000$
4B	Mixed-Dry	$\text{CDD}_{10\text{C}} \leq 2500$ & $\text{HDD}_{18\text{C}} \leq 3000$
4C	Mixed Marine	$2000 < \text{HDD}_{18\text{C}} \leq 3000$
5A	Cool-Humid	$3000 < \text{HDD}_{18\text{C}} \leq 4000$
5B	Cool-Dry	$3000 < \text{HDD}_{18\text{C}} \leq 4000$
5C	Cool-Marine	$3000 < \text{HDD}_{18\text{C}} \leq 4000$
6A	Cold-Humid	$4000 < \text{HDD}_{18\text{C}} \leq 5000$
6B	Cool-Dry	$4000 < \text{HDD}_{18\text{C}} \leq 5000$
7	Very Cold	$5000 < \text{HDD}_{18\text{C}} \leq 7000$
8	Subarctic	$7000 < \text{HDD}_{18\text{C}}$

Reference: Briggs, et al., Climate Classification for Building Energy Codes and Standards,
www.energycodes.gov.

REANALYSIS MODEL CELL VERSUS NCDC LOCAL -SITE GEOMETRY



REANALYSIS TEMPERATURES, WINDS, PRESSURES, ETC. MAY NEED LOCAL
CORRECTIONS IN MOUNTAINS & CITIES.

NOTE: Smaller 10-minute size cells are expected to follow actual terrain elevation profiles more closely; however, they still may not precisely match the elevation of a ground site within the 10-minute cell.

Figure 1. Height and horizontal influence of a local meteorological site in a valley within a 1-degree GEOS-4 cell in the mountains.

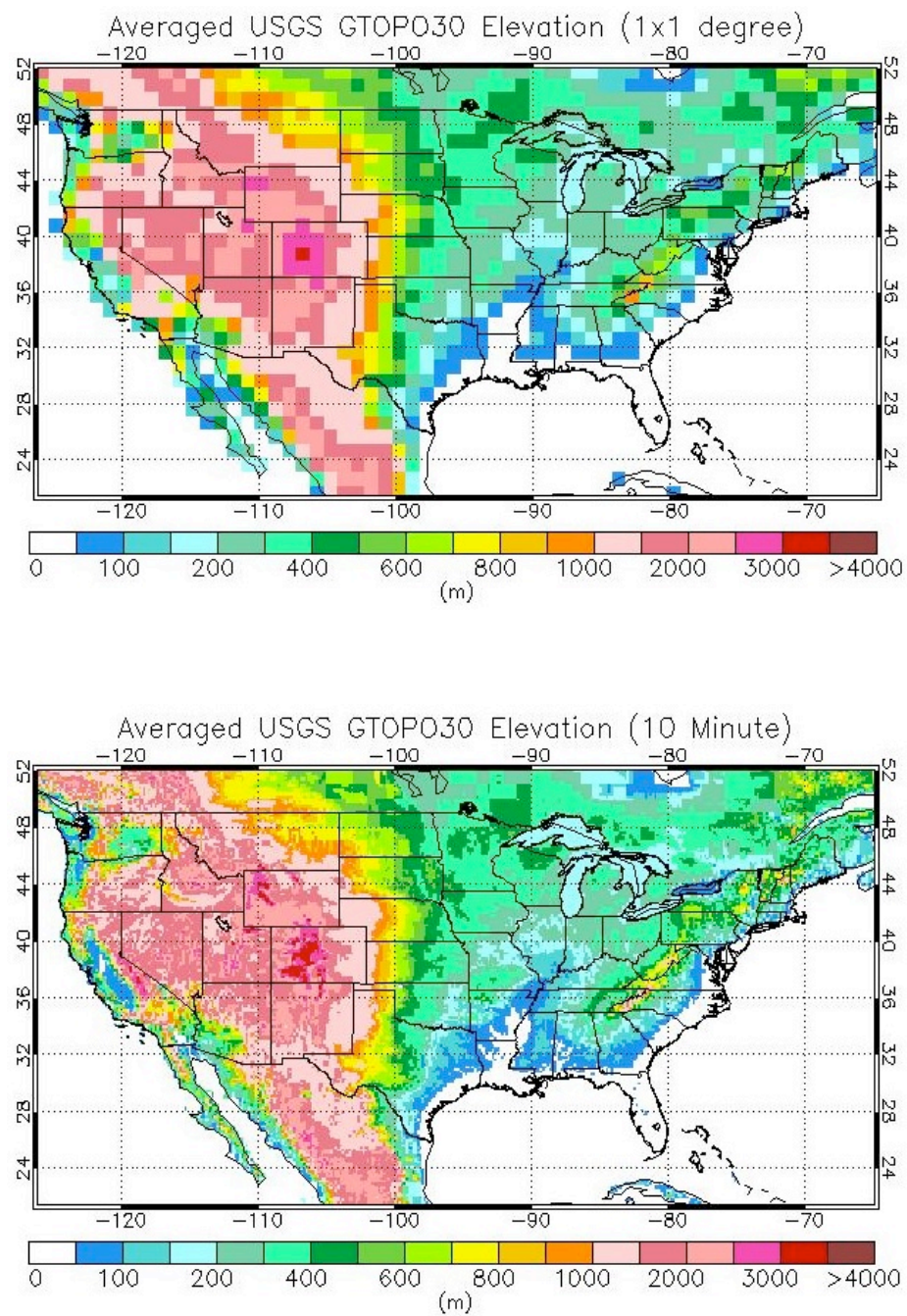


Figure 2. Comparison of U.S. topography maps for latitude-longitude cell sizes of 1 x 1 degrees and 10 x 10 minutes.

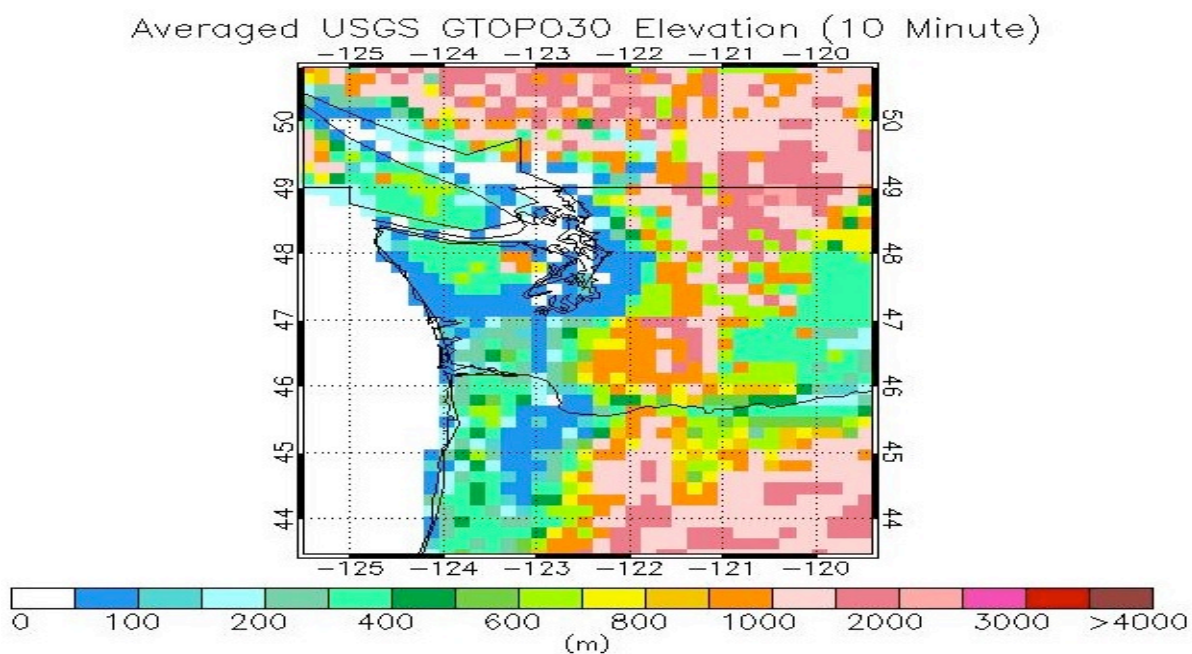
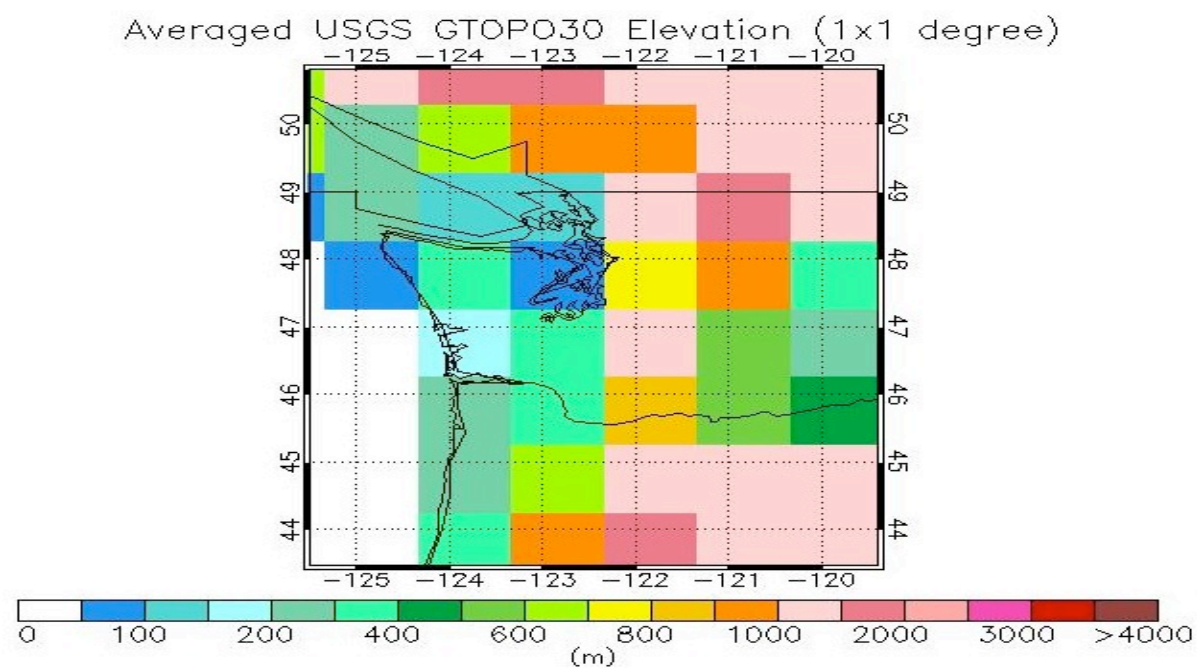


Figure 3. Comparison of topography maps for latitude/longitude cell sizes of 1 x 1 degrees and 10 x 10 minutes for the complex coastal/and mountain region in the northwestern United States and Canada.

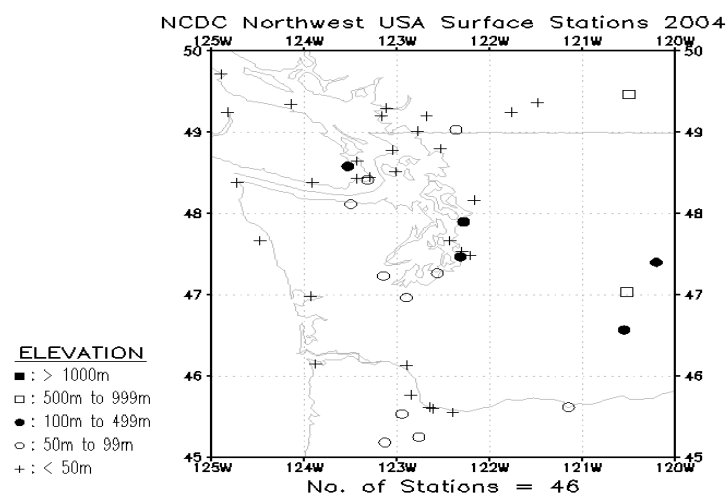
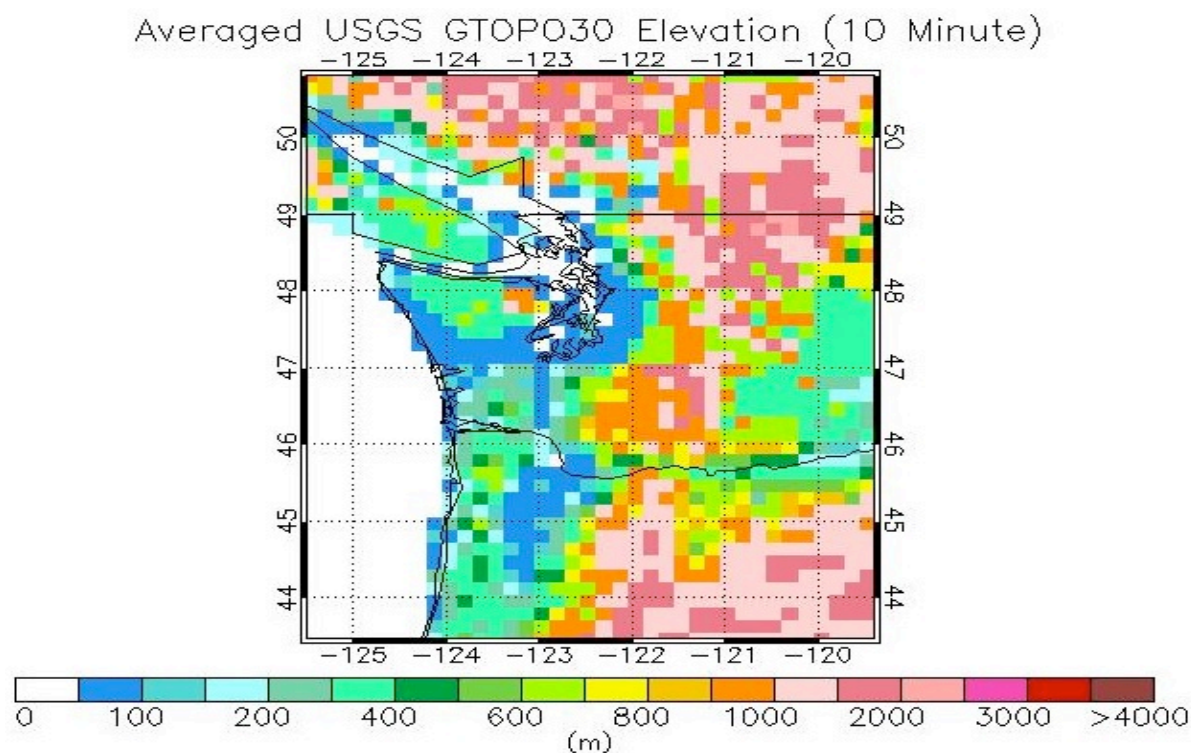


Figure 4. Location of NCDC ground sites relative to the 10-minute topography map for the complex coastal/and mountain region in the northwestern United States. Note that the maps do not cover the same region, but sizes have been adjusted to make distances between locations nearly identical.

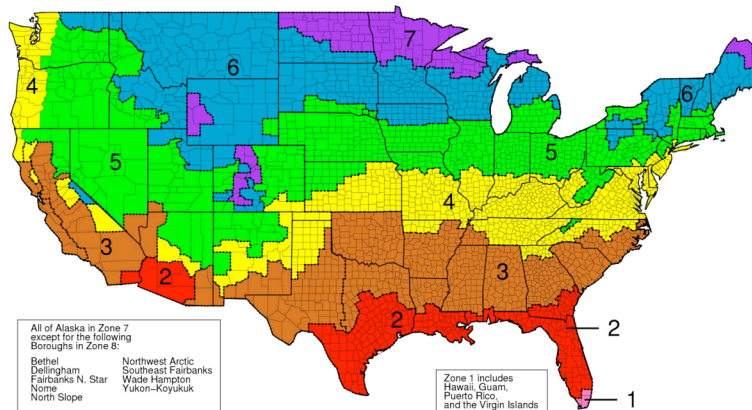


Figure 5. Climate zones (by county) based on 237 U.S. weather stations (SAMSON) covering the period from 1961 through 1990 (Briggs, Lucas, and Taylor, 2002) from U.S. Department of Energy web site: www.energycodes.gov.

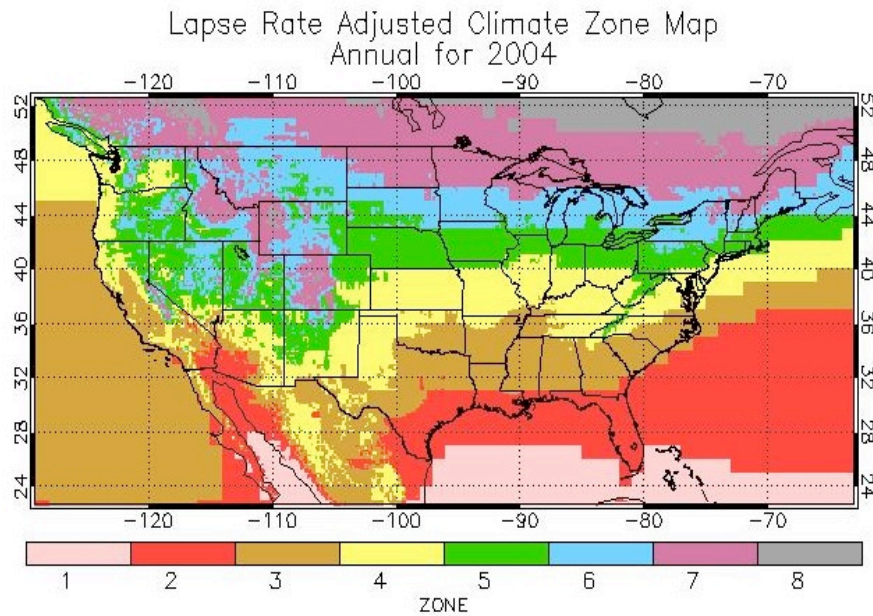


Figure 6. Climate zones based on NASA GEOS-4 1x1degree 2-meter reanalysis temperatures for 2004 which were then lapse-rate corrected to 10-minute-resolution topography.

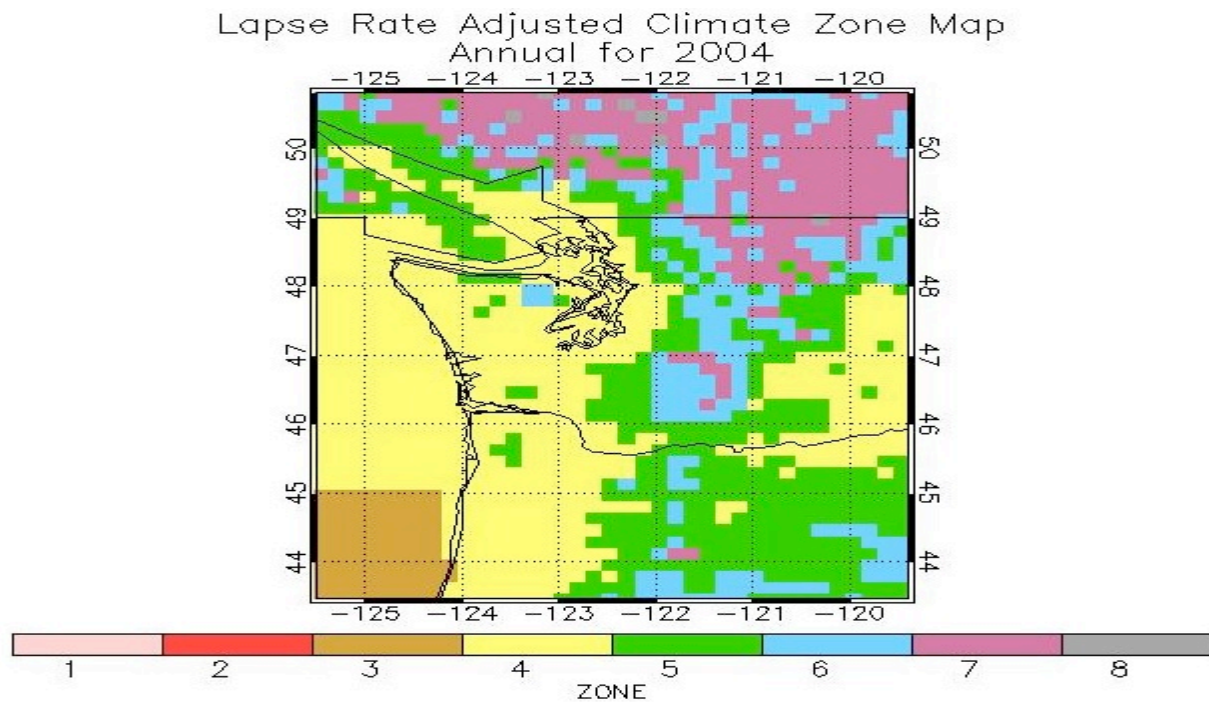
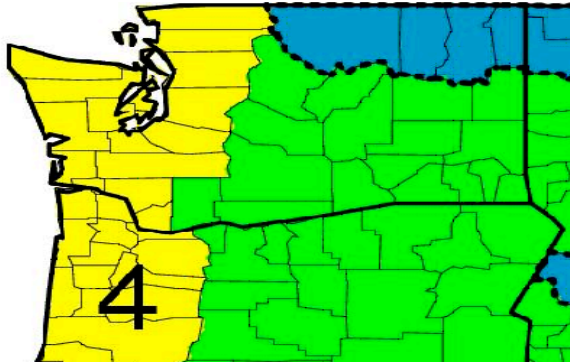


Figure 7. Comparison of Briggs et al. 30-year average (1961 through 1990) climate zones (Figure 4) with NASA GEOS-4 adjusted 10-minute cell-size climate zones (2004 only) for the complex pacific northwest region of the United States and Canada.

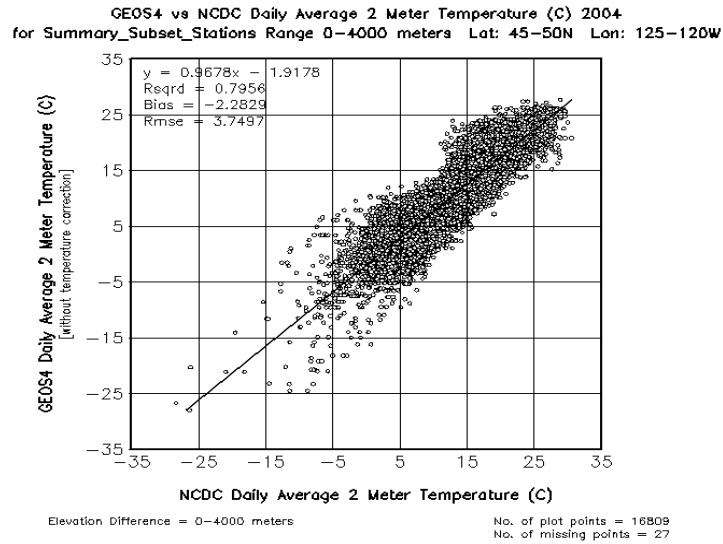


Figure 8. Comparison of uncorrected GEOS-4 2-meter height daily temperatures with NCDC site data in the northwest region of the United States and Canada for 2004.

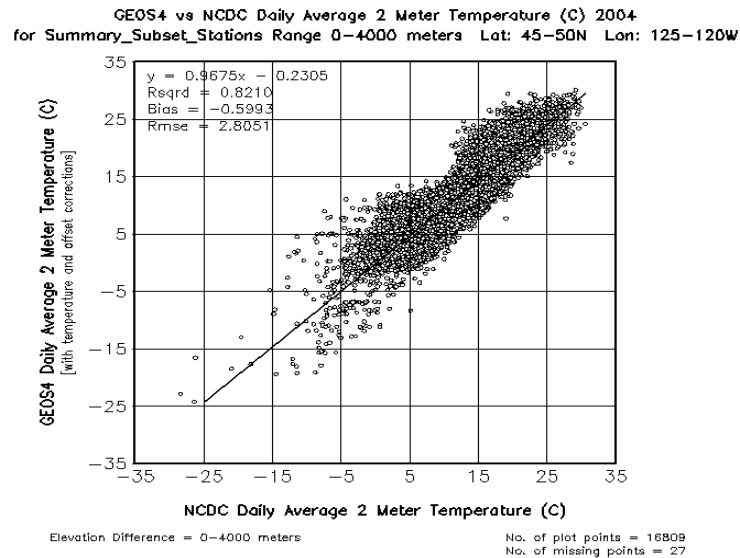


Figure 9. Comparison of corrected GEOS-4 2-meter height daily temperatures with NCDC site data in the northwest region of the United States and Canada for 2004.

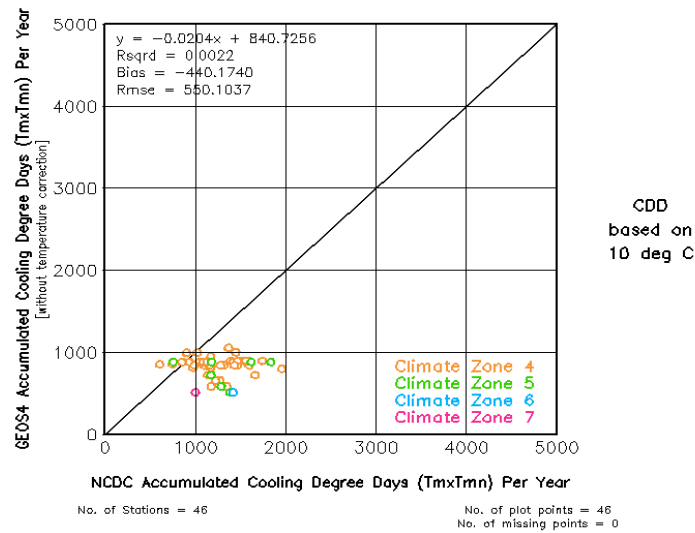
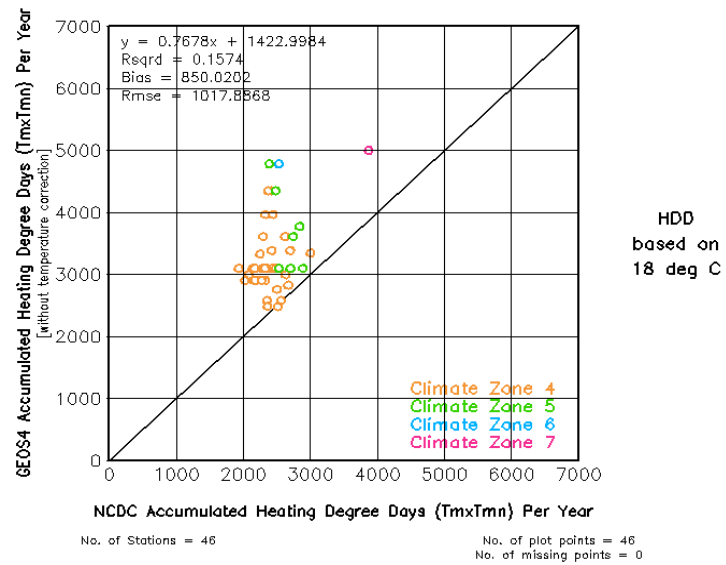


Figure 10. Comparison of uncorrected GEOS-4 2-meter height annual heating relative to 18 degrees C and cooling degree days relative to 10 degrees C with NCDC site data in the northwest region of the United States and Canada.

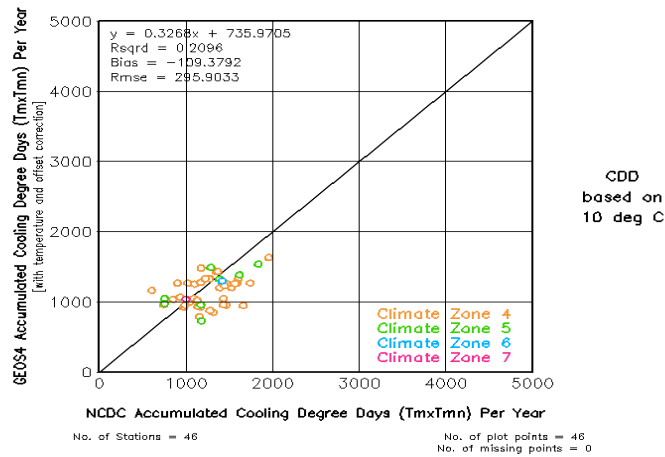
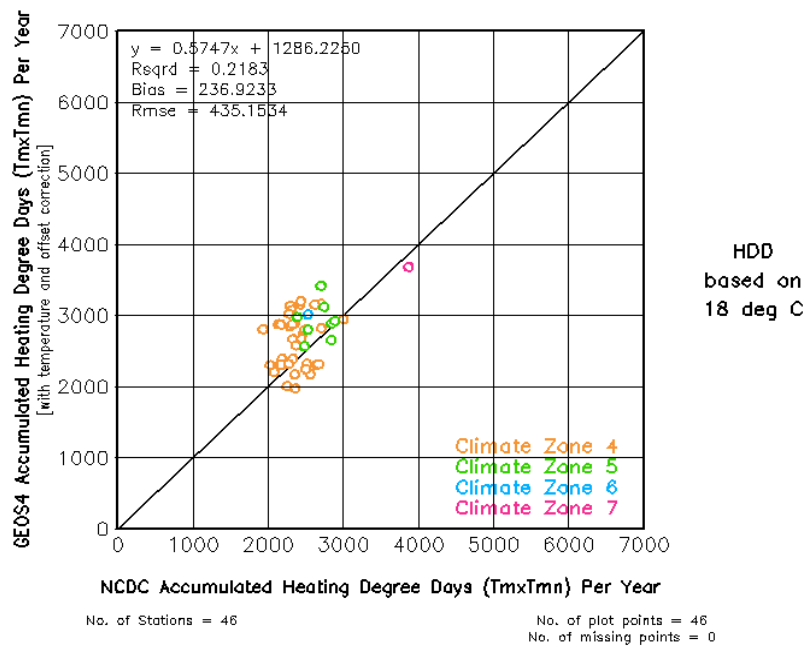


Figure 11. Comparison of corrected GEOS-4 2-meter height annual heating relative to 18 degrees C and cooling degree days relative to 10 degrees C with NCDC site data in the northwest region of the United States and Canada.

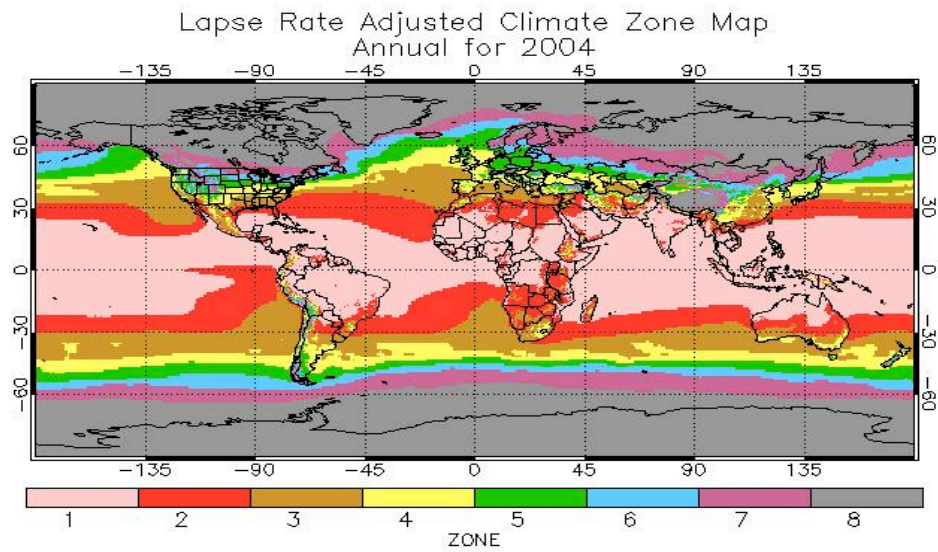


Figure 12. 10-minute cell size buildings climate zone estimates for the entire globe.

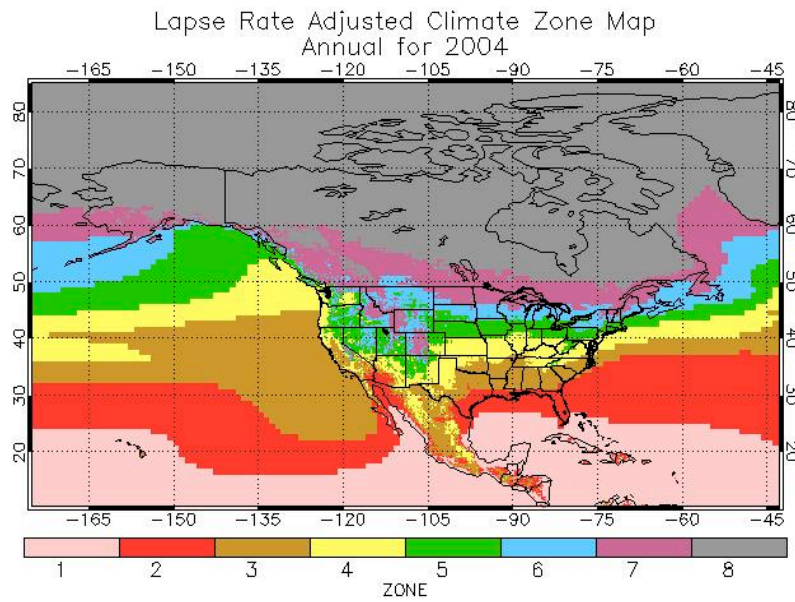


Figure 13. 10-minute cell size buildings climate zone estimates for North America.

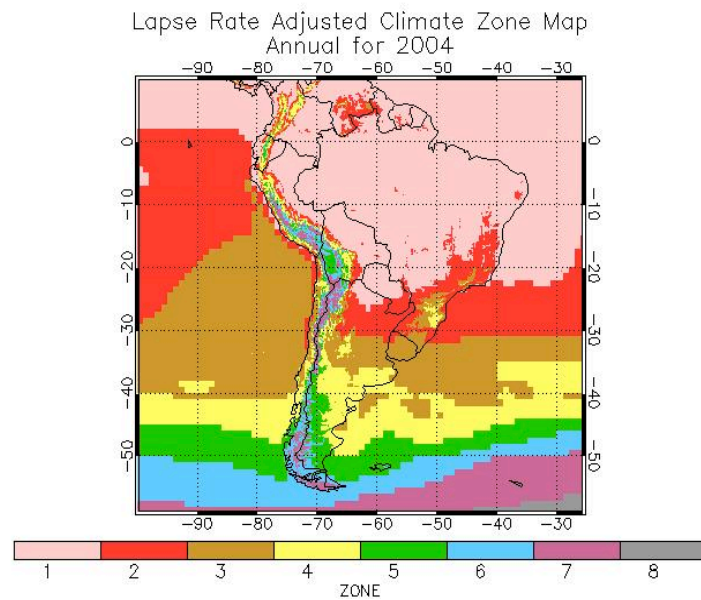


Figure 14. 10-minute cell size buildings climate zone estimates for South America.

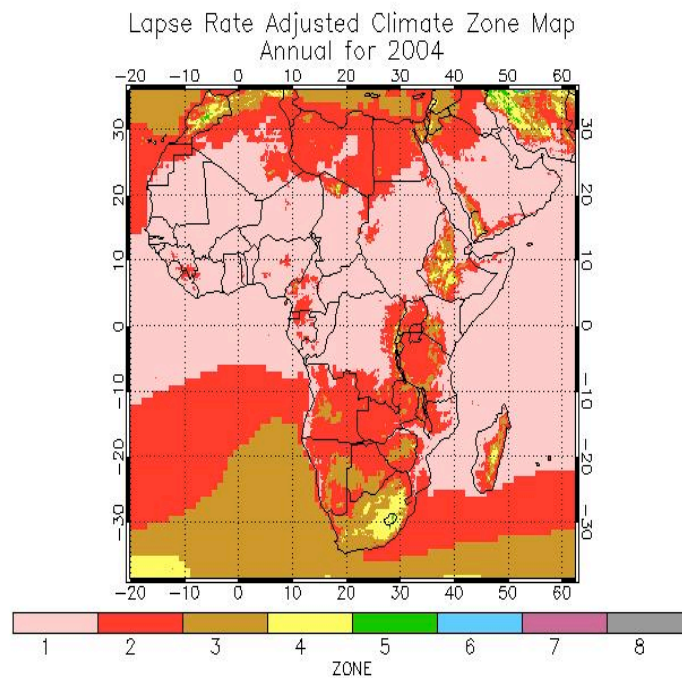


Figure 15. 10-minute cell size buildings climate zone estimates for Africa.

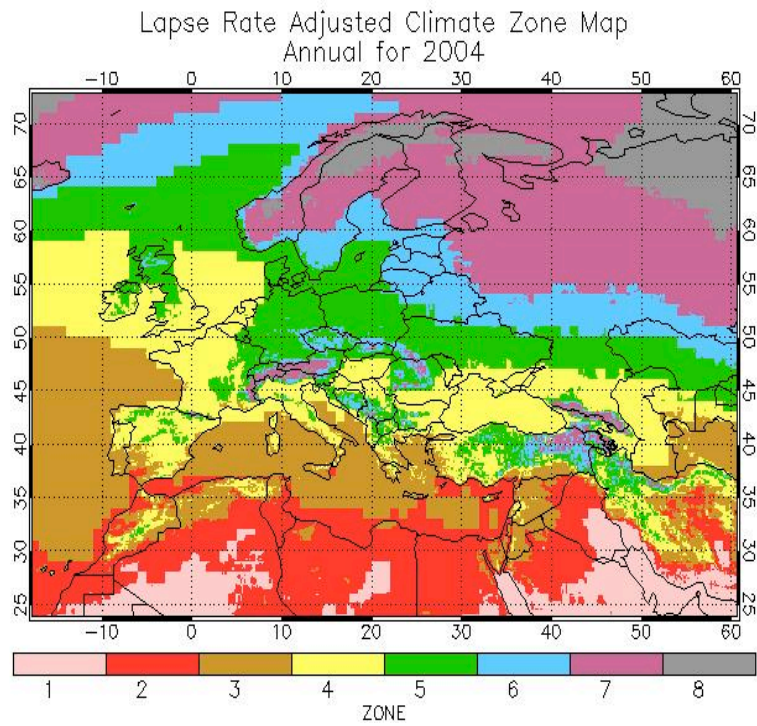


Figure 16. 10-minute cell size buildings climate zone estimates for Europe.

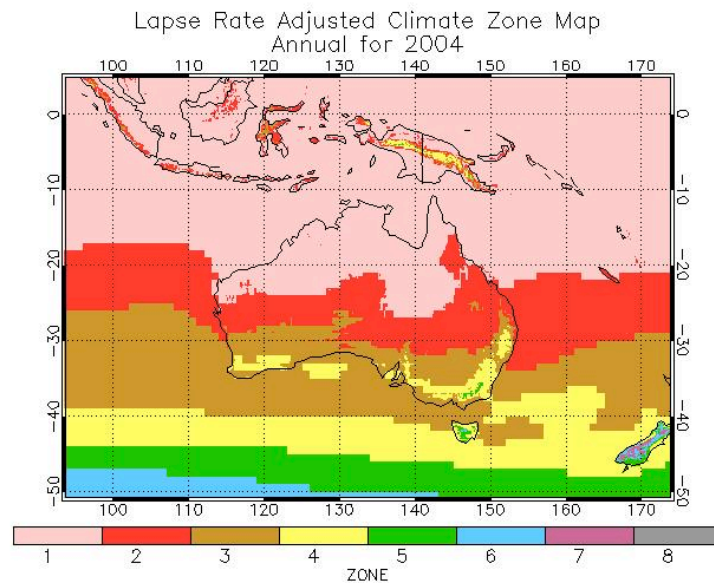


Figure 17. 10-minute cell size buildings climate zone estimates for Australia and the South Pacific.

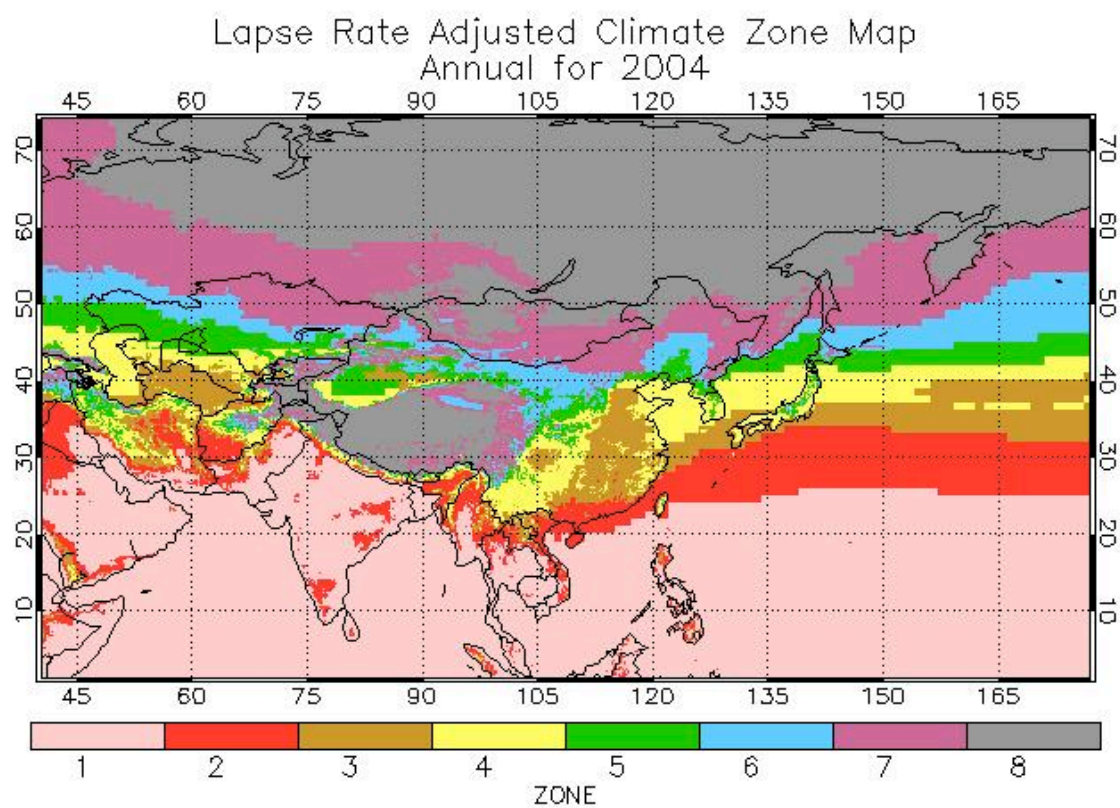


Figure 18. 10-minute cell size buildings climate zone estimates for Asia.